Mission Success Starts with Safety

Reliability and Maintainability – The Key to Affordability for Launch Vehicles

The Annual Reliability and Maintainability Symposium 2014

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Agenda

- History of Reliability and Maintainability
- The Reliability Engineering Case
- The Maintainability Engineering Case
- Cost of Ownership
- R&M Relationship to Safety and Affordability
- NASA Lessons Learned
- Concluding Remarks

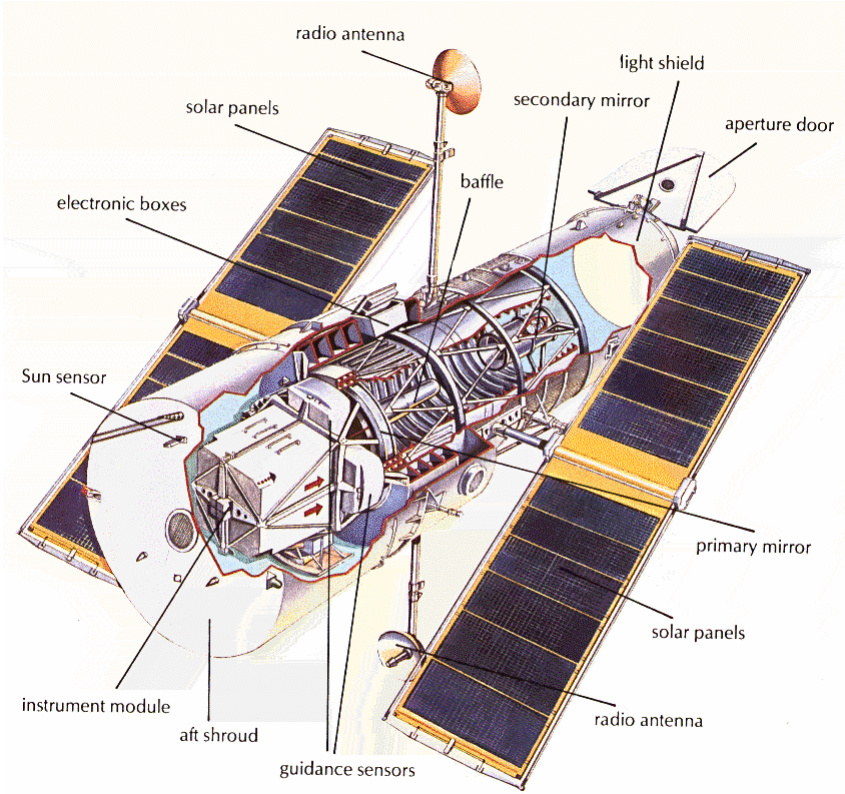
History of R&M Engineering at NASA

Reliability engineering has played a key role in NASA mission success since the early Apollo days.

During the Apollo days, reliability engineers performed FMEA and Criticality analysis, prediction, and failure analysis.

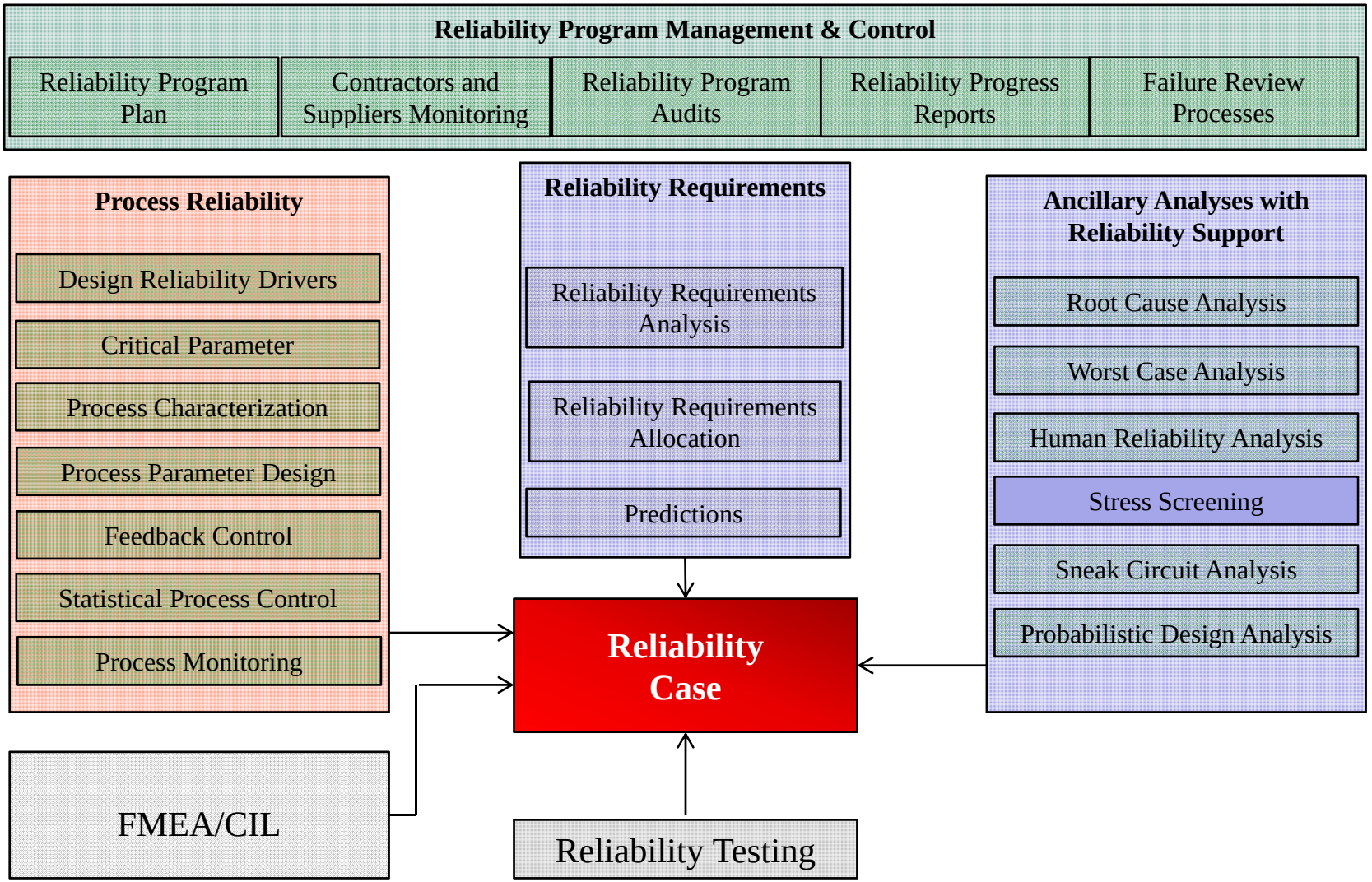
History of R&M Engineering at NASA

Maintainability concepts were included early in the life cycle, where maintenance planning and optimum ORU usage in design saved the program significant costs when on-orbit repairs became necessary.

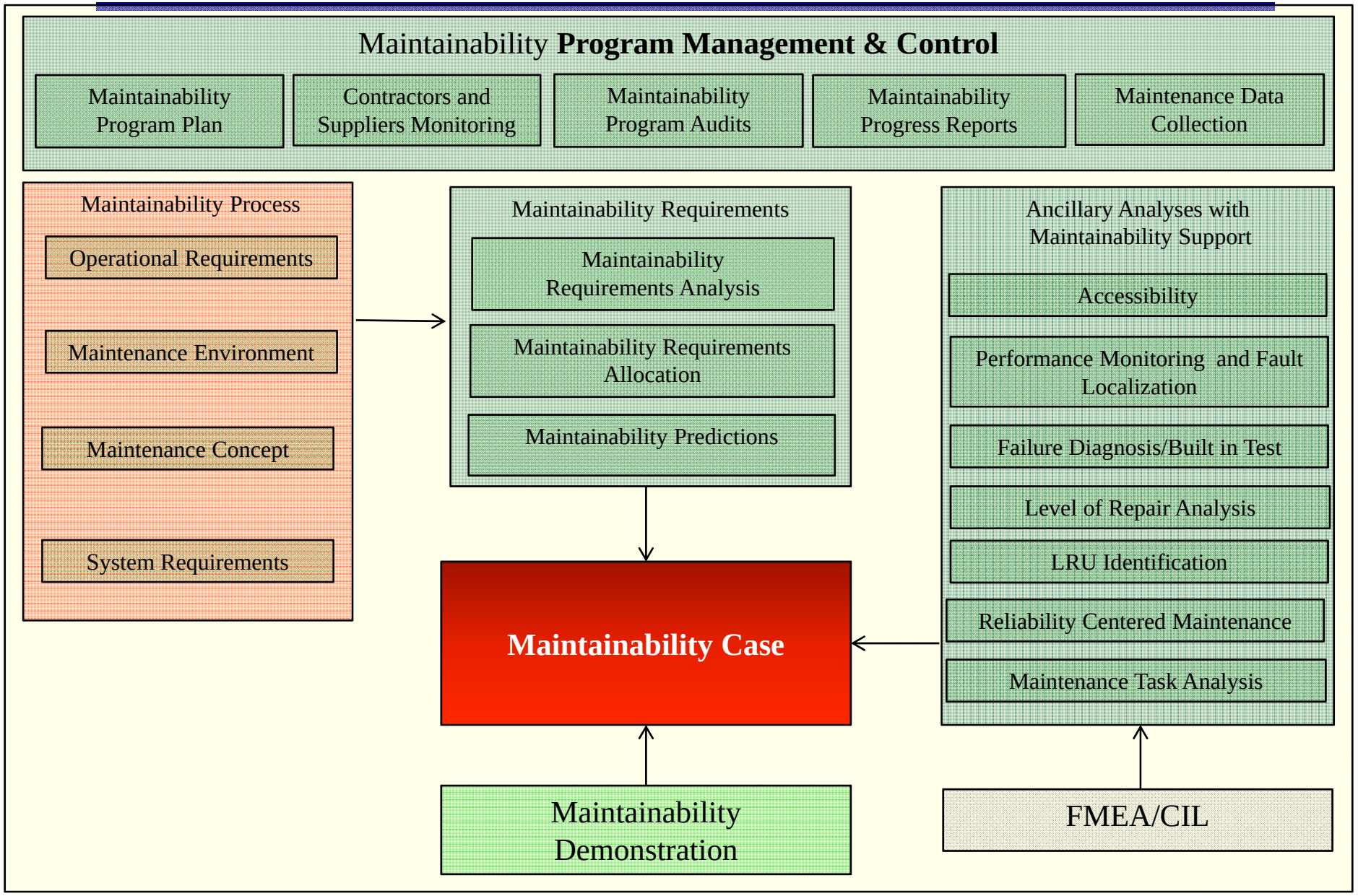


HST was designed with replaceable cameras and guidance sensors. Provisions were also made for change-out of limited life components (e.g. gyroscopes, batteries, and reaction wheels). Servicing missions were planned every three years using the Space Shuttle. In this way the initial expense of developing and launching the HST would be amortized over a longer lifetime while providing a consistent level of scientific return by incorporating the latest technologies.

The Reliability Engineering Case

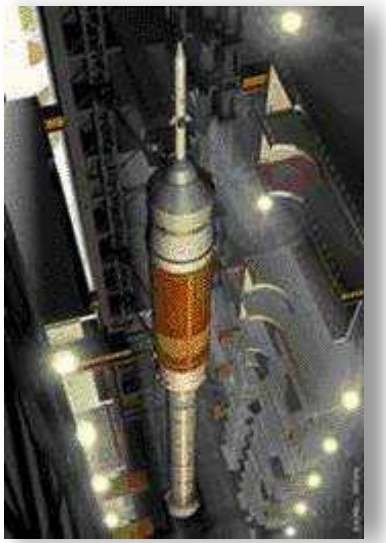


The Maintainability Case

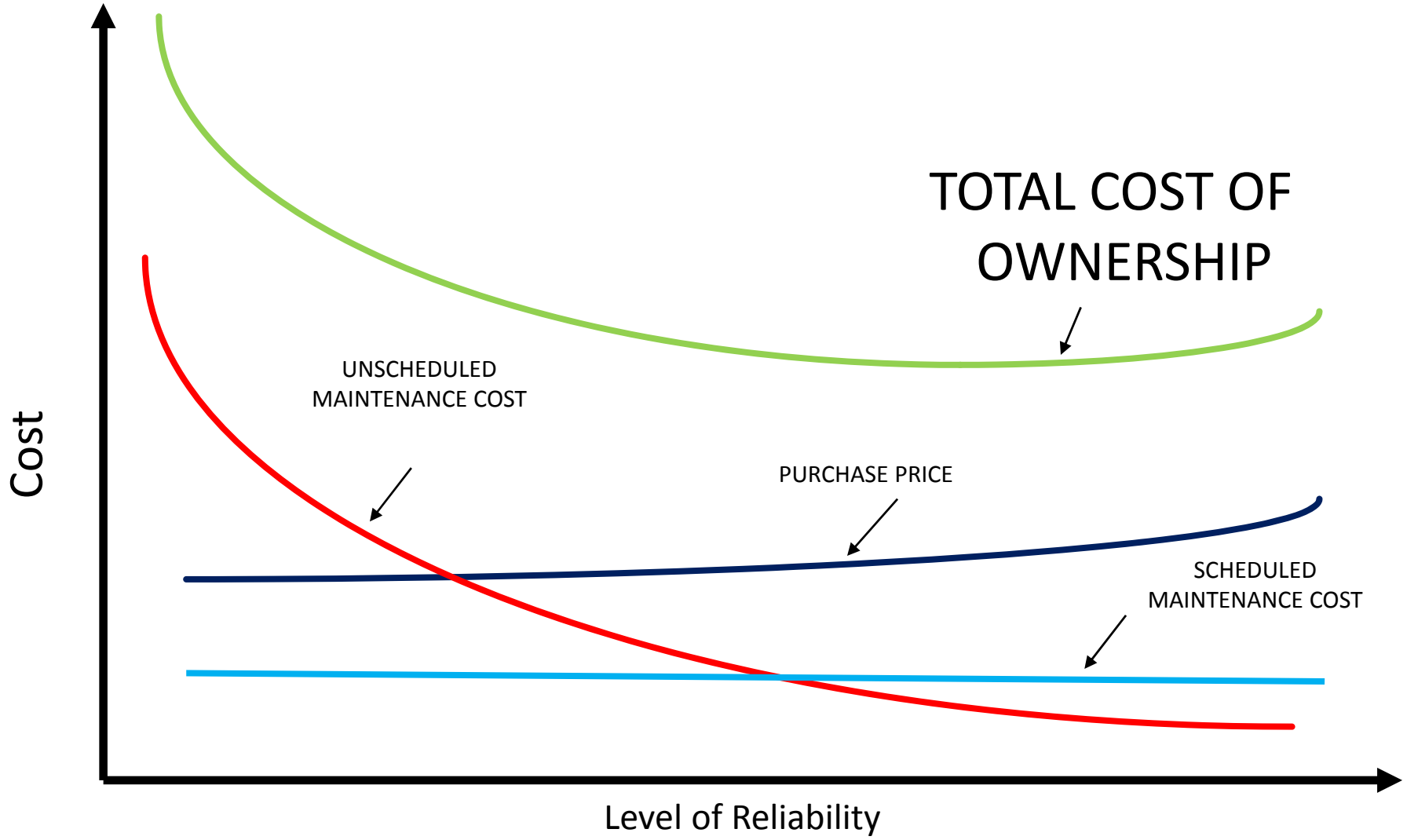


Total Cost of Ownership

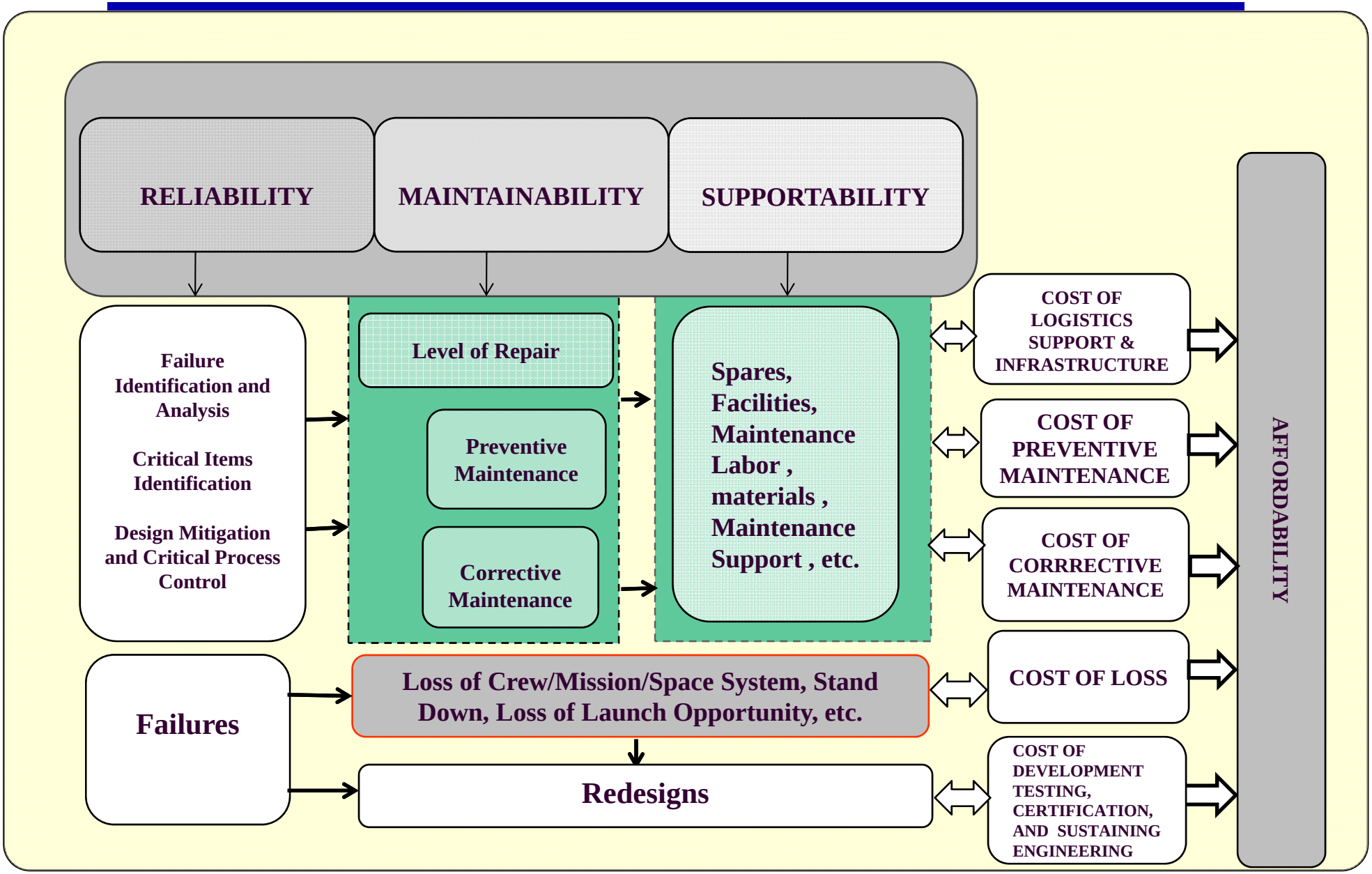
- Initial purchase price, cost of design, development, assembly, integration, test, and checkout
- Scheduled maintenance costs
- Salvage values
- Unscheduled maintenance costs
- Cost of lost operations
- Indirect time of unscheduled maintenance



R&M Contribution to Total Cost of Ownership



R&M Relationship to Safety and Affordability



Cost-benefit analysis

skb2

- **There is a real risk in accepting the cheapest Life Cycle Cost (LCC) option without considering how many of the requirements have been sacrificed in comparison with other, more expensive options.**
- **A cost-benefit analysis identifies the most cost-effective solution of those available.**
- **Key Reliability & Maintainability drivers in a LCC trade-off :**
  - operational availability
  - spares cost
  - manpower cost
  - probability of mission success
  - support cost

Slide 10

skb2 Replace cheapest with lowest.
Replace sacrificed with comprimised.
Replace 'more expensive options' with 'more cost-effective options'.
skbrouss, 7/24/2013

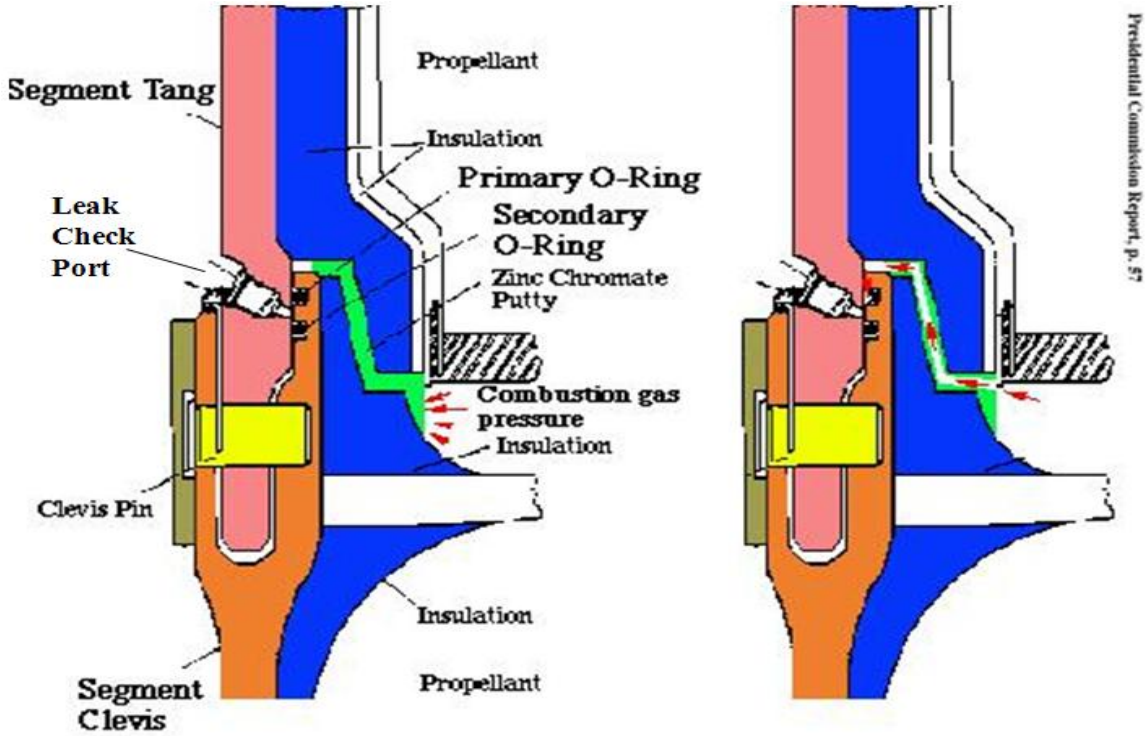
Space Shuttle Lessons Learned

“While the Shuttle's capabilities are extensive and varied, it has proven to be extremely expensive to use, unreliable in its logistics, and operationally fragile.”

Testimony of Michael D. Griffin
Hearing on the Future of Human Space Flight Committee on Science
Rayburn House Office Building Room 2318 16 Oct 2003

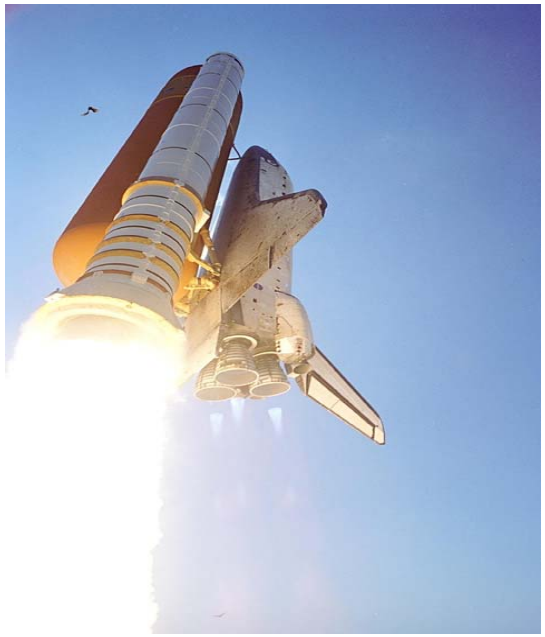
NASA Lessons Learned
The Challenger Case

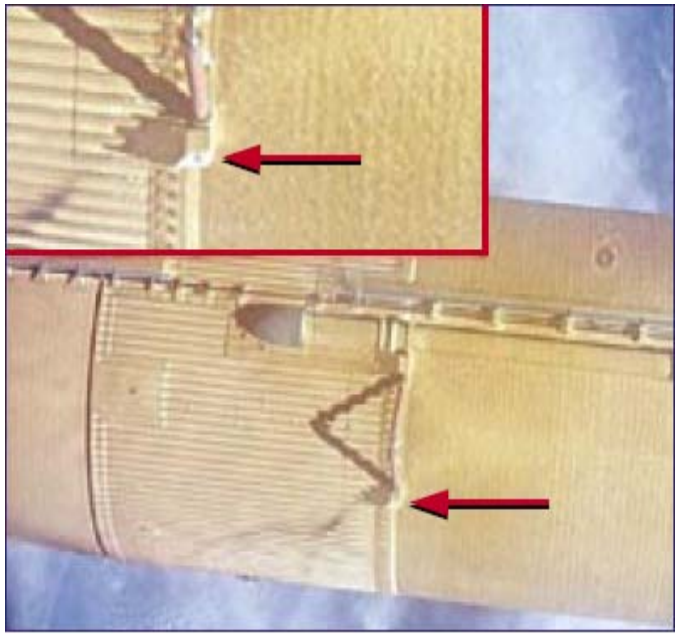
- **Causes and Contributing Factors**
  - The zinc chromate putty frequently failed and permitted the gas to erode the primary O-rings.
  - The particular material used in the manufacture of the shuttle O-rings was the wrong material to use at low temperatures.
  - Elastomers become brittle at low temperatures.



NASA Lessons Learned
The Columbia Case

- **Causes and Contributing Factors**
  - Breach in the Thermal Protection System caused by the left bipod ramp insulation foam striking the left wing leading edge.
  - There were large gaps in NASA's knowledge about the foam.
  - cryopumping and cryoingestion, were experienced during tanking, launch, and ascent.
  - Dissections of foam revealed subsurface flaws and defects as contributing to the loss of foam.



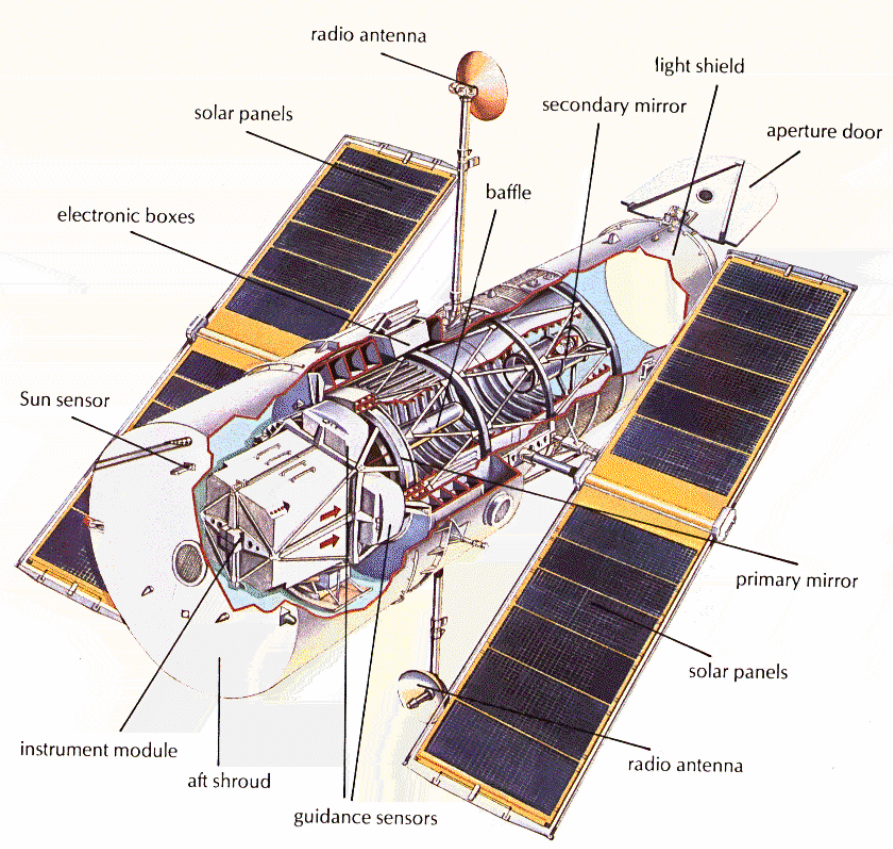


NASA Lessons Learned

The Hubble Space Telescope Success Story

Implementation of maintainability principles can increase operational availability and reduce LCC

- Enhanced System Readiness/Availability
- Reduced Downtime
- Supportable Systems
- Ease of Troubleshooting and Repair
- System Growth Opportunities
- Hardware/Software Modifications
- Interchangeability
- Modular Designs
- Decreased Storage Considerations
- Reduced Maintenance Manpower
- Reduced Operational Costs
- Compatibility with other Programs
- Reduced Management Overhead



Hubble Space Telescope was designed for Maintainability and Serviceability. Launched in 1990 it is still functioning today.

Concluding Remarks

- R&M is extremely critical to build safe, reliable, and cost effective systems.
- The challenges of today's unmanned and manned space flight programs demand the most efficient use of our technical knowledge base to develop cost effective and affordable systems.
- An efficient reliability and maintainability program is essential to meet the challenges for the nation's Space Program.
- Lessons learned from the NASA programs clearly demonstrate the importance of reliability and maintainability engineering in designing and operating safe and affordable launch systems.